

Wireless!

The forces and strategies that shaped a revolution



Lecture 19- Unlicensed Spectrum- New Products and Economics

Lecture 19- Classwork

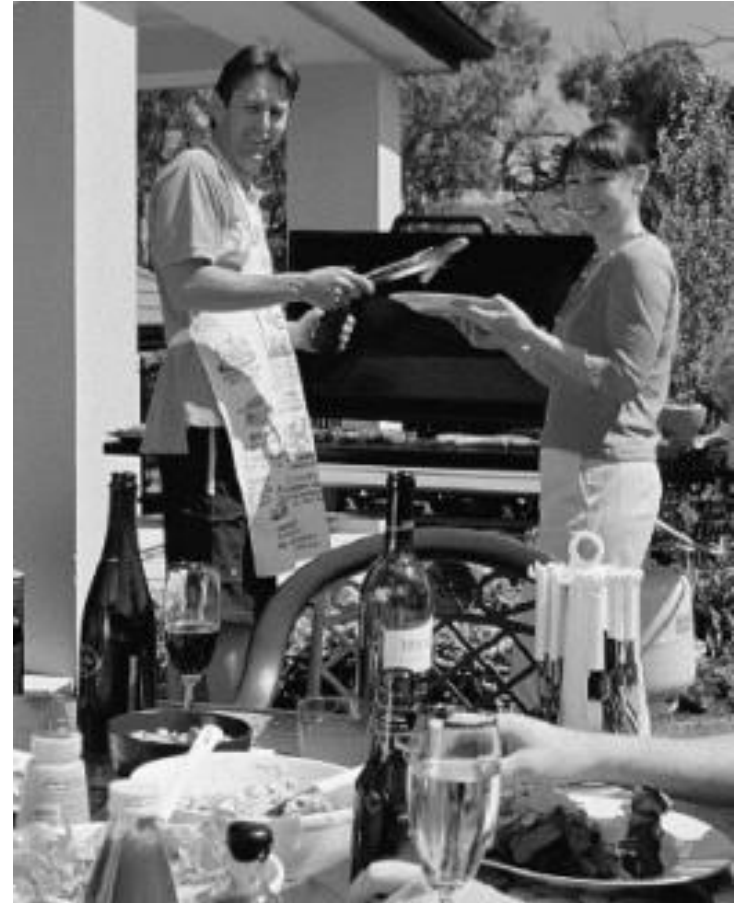
1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 19 including some important takeaways from your reading.
2. Why did cellular systems need exclusive licenses for their channels? **Q2**
3. Why did cordless phones not require compatibility standards in the early days? Why did some compatibility standards emerge over time?
4. What caused CB radio to experience increasingly higher levels of interference and lose popularity while cordless phones did not?
5. Why did WiFi need more compatibility standards than cordless phones?
6. Why did Bluetooth evolve into niche applications different from WiFi?

Licensed vs. unlicensed spectrum

- ❑ Licensed spectrum gives specific entities permission to use that spectrum in specific ways in specific places
 - Cellular systems are licensed because they are expensive to create and vulnerable to interference, so the operator gets exclusive use of the channels in a particular area.
 - Other regulations (e.g., for nationwide compatibility) may or may not be included
- ❑ Unlicensed spectrum is used in cases where devices are unlikely to cause problems for one another
 - Different products may be allowed on the same channel
 - Regulation is minimal (limitation to low power is common)
 - Time to market is minimal
 - Other regulations are added when appropriate

Cordless phones

- ❑ **Cordless telephones**
 - **10 channels below 50 MHz (TV chan 2)**
 - **Phones at the barbeque**
 - **Other products like baby monitors and garage door openers were allowed on the same channels**
- ❑ **Early quality problems**
 - **Very low power; short range**
 - **interference from other nearby phones**
- ❑ **Quality finally improved; millions sold**
 - **Had become the predominant home phone in US and the world**
 - **Until cellular began to erase wired telephony**



The tiny cordless “cell”



CB radios

- ❑ CB (Citizen's Band) radio
 - 40 channels at 27 MHz
 - 4 watts; Possible Range of few miles
 - A social phenomenon ("Convoy")
 - "pedal to the metal" and "good buddy"
 - A safety device for drivers
 - Millions sold
 - Interference became a problem
 - Market collapsed in early 1980s



Q4

Why was CB different from cordless?

CB needed more range: “bigger cells”



- ❑ While cordless phones only need about 50-100 foot range, CB needed hundreds of feet or even miles of range.
- ❑ If we assume a range of 100 feet for Cordless and 5000 feet for CB, cordless has 2,500 times the channel reuse of CB, yet for the two applications the number of channels were in the same ballpark (10 vs. 40).
- ❑ As a result, when demand grew to millions of users, cordless continued to work well, but CB got congested and lost its usefulness.
- ❑ Since early systems, cordless has operated in 900 MHz, 1.9 GHz, 2.4 GHz and 5.8 GHz

The strategic lesson of cordless for spectrum regulation

- ❑ Short range products can organize themselves to avoid interference
 - Find another channel
- ❑ They can provide huge capacity
 - Tiny “cells”
- ❑ They don’t require a lot of rules (do no harm)
 - Low power is the main rule
 - Low antennas as well
- ❑ Can even mix applications in the same area (with some care)
 - Inherently poor “mixes” can coexist, though planning helps (a continuing tension between planning and getting to market)

Applying the lesson to the ISM bands

- ❑ What are the ISM bands?
 - “Industrial, scientific, medical”
 - Set aside for emitters of radio noise, to prevent interference with radio communications services
 - ❑ Microwave ovens; medical diathermy; drying lumber
 - Studies showed little interference in most places
- ❑ An opportunity for “unlicensed” products like cordless phones and WiFi
 - Users at risk; no recourse if interference exists
 - An emphasis on trying new things
- ❑ The most useful bands were at 900MHz and 2.4 GHz
 - Useful for propagation; as much spectrum as cellular!
 - Free spectrum while cellular pays billions!

A testing ground for new ideas

- ❑ Products on the shelf in less time than a round of FCC hearings on cellular
- ❑ A chance for “innovative chaos”
 - From garage door openers, cordless phones and baby monitors to meter readers, toll takers, home control and security, to WiFi and Bluetooth
 - Few options for long range; so bands have huge capacity
- ❑ Based on the success of WiFi, 300 MHz of additional spectrum was added at 5GHz in the so-called U-NII band
 - Your personal WiFi has much more available spectrum than a cellular base station serving 1000 users
 - WiFi capacity is virtually unlimited, and almost free

How does Wi-Fi work? CSMA

- ❑ Carrier Sense Multiple Access (CSMA) is a medium access control (MAC) protocol that allows multiple devices to share a communication channel- "Listen Before Talk"
- ❑ Carrier Sensing: Before transmitting, a device "listens" to the channel to see if it's **busy** (another device is transmitting) or **idle**
- ❑ Multiple Access: **If channel is idle, device can transmit data. If the channel is busy, don't transmit**
- ❑ Collision Avoidance: If multiple devices try to transmit at the same time, a collision occurs
- ❑ CSMA protocols include mechanisms to detect and resolve collisions: **e.g., by retransmitting data after a random delay**

Roadmap of WiFi Technology Evolution

- WiFi Evolution in Time: 7 Main Generations

1G: 802.11b 1999	2G: 802.11a 1999	3G: 802.11g 2003	4G: 802.11n 2009	5G: 802.11ac 2013	6G: 802.11ax 2020
MAC: CSMA Phy: DSSS F: 2.4 GHz ISM Ch. BW: 20 MHz Speed: Slow up to 11 Mbps Range: indoor: 35m outdoor: 140m	MAC: CSMA Phy: OFDM F: 5 GHz ISM Ch. BW: 20 MHz Speed: Medium up to 54 Mbps Range: indoor: 35m outdoor: 120m Not Compatible with 802.11b	MAC: CSMA Phy: OFDM F: 2.4 GHz ISM Ch. BW: 20 MHz Speed: Medium up to 54 Mbps Range: indoor: 38m outdoor: 140m Compatible with 802.11b	MAC: CSMA Phy: MIMO/OFDM F: 2.4, 5 GHz ISM Ch. BW: 20/40 MHz Speed: High up to 450 Mbps Range: in: 70m, out: 250m Compatible with 802.11b,a,g 64 QAM 4*4 MIMO	MAC: CSMA Phy: MU-MIMO/OFDM F: 5 GHz ISM Ch. BW: 20/40/80/160 MHz Speed: Very High up to 3.47 Gbps Range: in: 35m out: 120m Compatible with 802.11a,n 256 QAM 8*8 MIMO	MAC: OFDMA Phy: MU-MIMO/OFDM F: 2.4, 5 GHz ISM Ch. BW: 20/40/80/160 MHz Speed: Very High up to 10 Gbps Range: in: 30m out: 120m Compatible with all Better Signaling for low RSSI 1024 QAM 8*8 MIMO

❑ 7G (WiFi7): 802.11be Current standard has been finalized

❑ Works across all three bands (2.4 GHz, 5 GHz, and 6 GHz)

So WiFi was a big winner

- Broadband Internet access in homes and businesses
- Increasing public access at restaurants, hotels and schools
- Range up to a few hundred feet (mostly less); a lot of reuse
- Physical setting provides some separation from interference
- The walls of your home or business keep interferers away (physically) (like a tiny cell with restricted access)
- Broadband (WiFi) channels can transmit at more than 100 Mbps
 - ▣ A movie in a minute or two
 - ▣ A month's worth of smartphone usage in 5 minutes

But WiFi must be short range

❑ Wide channels require more power

- ❑ Range for a radio is limited by “signal-to-noise” ratio
- ❑ Noise can be natural or man-made, but “noise power” is there in every MHz of spectrum
- ❑ A wider channel has proportionately more noise to overcome, and requires more signal power to achieve the same range.
- ❑ For the same range, twice the bandwidth needs twice the power- like sending two channels.

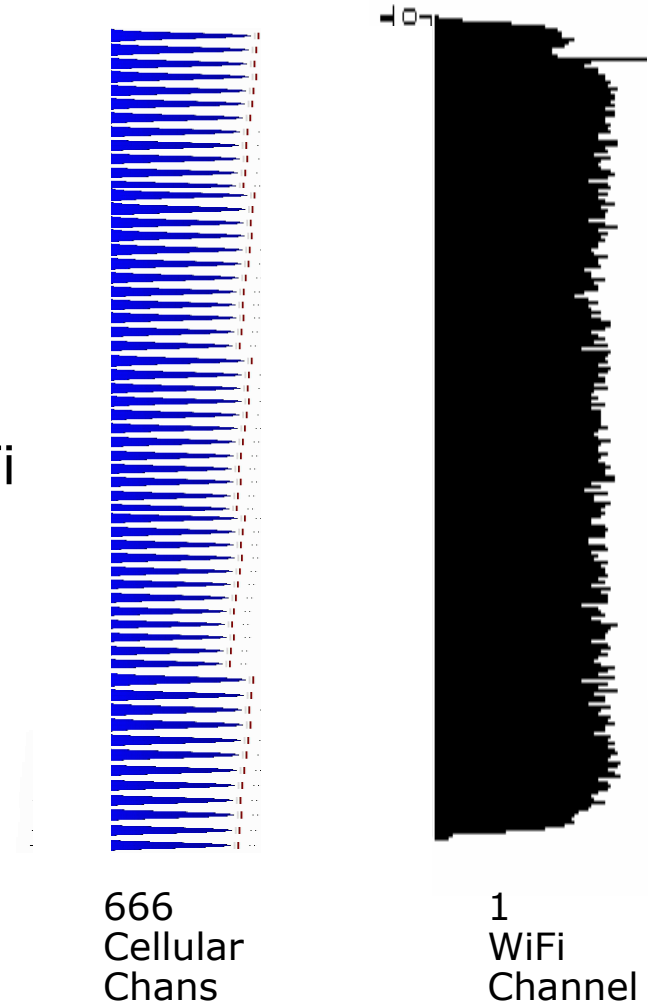
WiFi channels are pretty wide

If a 30 KHz voice channel requires a tenth of a watt to achieve a 1-mile range, a 20 MHz WiFi channel would require 66 watts for the same range.

This amount of power would drain the battery of a cell phone or laptop in seconds.

It would also destroy the usefulness of WiFi by allowing only one user in a large area.

WiFi must be short-range!



Cellular and Unlicensed

The polar extremes of spectrum regulation

- ❑ Cellular was a triumph of technology, standards and regulation (and expensive licensed spectrum)
 - Wide Area Networks (WANs)
- ❑ WiFi was a triumph of minimal regulation, innovation and market competition (and cheap unlicensed spectrum)
 - Local Area Networks (LANs)
- ❑ 3G cellular offers Internet access anytime/anywhere, but costs too much (and doesn't have the capacity) for rich video
- ❑ WiFi has limited coverage, but is cheap and has plenty of capacity for rich video.

Did “WiFi” offer a solution to the “3G problem”?

The \$1.5M 3G/4G Cell vs. the \$100 WiFi Modem

3G/4G Cell

Investment: \$1.5M (with new technology + spectrum costs)

Speed: 50 Mbps for a base station*

Investment /Mbps: = \$30,000

802.11 WiFi modem

Investment: \$100 (free spectrum)

Speed: 20 MHz @
1.5-3 bits/sec/Hz = 30-60 Mbps**

Investment /Mbps: = \$1.6-\$3.3

**The investment to create 1 Mbps downloads is
10,000 times cheaper for WiFi !!**

*Assuming 1/15th of the spectrum allocation per cell and 7.5 bits/sec/Hz, new spectrum of 100 MHz for the system, yields 50 Mbps/cell. WiFi can use the whole 20 MHz in every location.

** Many WiFi devices advertise much higher rates (in particular when the transmission path is short).

Can we use this low cost device to increase cellular capacity?

The WiFi “hotspot”– The cellular operators WiFi solution

- A much needed “solution” in a desperate attempt to get some traffic off their systems
- Needs thoughtful design
 - Hot spots must be available when traffic is high
 - Users must stop and wait for full benefits

ECONOMIC VALUE COMPARISON: Wi-Fi vs. CELLULAR (USA)

Wi-Fi

LOCALIZED HIGH-CAPACITY & EFFICIENCY.

RESIDENTIAL & ENTERPRISE SAVINGS

ESTIMATED ANNUAL VALUE (U.S.)
> \$1.2 TRILLION GDP CONTRIBUTION
(e.g., from customer savings, producer surplus)



DATA TRAFFIC EFFICIENCY

OFFLOADS **~75-90%**
OF MOBILE DATA

CELLULAR
COST SAVINGS
(ANNUAL)



SPECTRUM UTILIZATION

UNLICENSED BANDS
(e.g., 2.4, 5, 6 GHz)

INCREMENTAL
VALUE FROM
6 GHz BAND

\$800B+
6 GHz BAND
(2023-24)



WI-FI CONNECTS AT WORK

COMPARISON POINTS

MAIN PURPOSE

COVERAGE AREA

ECONOMIC IMPACT

USER COSTS



CELLULAR (e.g., 5G/4G LTE)

WIDE-AREA MOBILITY & CONNECTIVITY.

GDP CONTRIBUTION & INVESTMENT

ANNUAL CONTRIBUTION (U.S.)
~\$700 BILLION to U.S. GDP

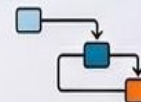


CRITICAL MOBILITY & COVERAGE



\$130B+ ANNUAL CONSUMER
FROM 4G NETWORKS

NEW BUSINESS MODELS



\$30B+ INFRASTRUCTURE
INVESTMENT



CELLULAR CONNECTS EVERYWHERE

*Estimates based on aggregated data. Sources: Industry reports and government studies.

Slide 4

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Wi-Fi 7 IEEE 802.11be (2024)

- ❑ **Wider 320 MHz channels:** (double the width of Wi-Fi 6's 160 MHz channels) and 4K QAM (4096-quadrature amplitude modulation), allowing for more data to be packed into each signal, resulting in **higher throughput and lower latency**.
- ❑ **Multi-Link Operation (MLO):** Connect across multiple frequency bands (2.4 GHz, 5 GHz, and 6 GHz) simultaneously, improving load balancing, increasing throughput, and enhancing reliability.
- ❑ **Increased Capacity:** supports 16x16 MU-MIMO (Multi-User MIMO antennas)
- ❑ **Applications:** 4K/8K video, online gaming, immersive AR/VR experiences, large number of connected devices in homes and businesses.
- ❑ Backward Compatibility

Bluetooth- the technology for peripherals

- ❑ Short range wireless technology standard for exchanging data between fixed and mobile devices over short distances
- ❑ Personal area networks (PANs)
- ❑ ISM bands 2.402 GHz to 2.48 GHz (same as WiFi 802.11 b/g)
- ❑ Typically, transmission power is limited to 2.5 milliWatts
- ❑ Maximum range $\sim$ 10 meters (33 ft)
- ❑ Alternative to wired connections, to exchange files between nearby portable devices, e.g. cell phones, music players, wireless headphones

How does Bluetooth work?

- ❑ **Frequency Hopping:** To avoid interference and maintain a reliable connection, Bluetooth uses a technique called frequency hopping, where devices rapidly switch between different frequencies within the 2.4 GHz band
- ❑ **Pairing:** Before two Bluetooth devices can communicate, they must first be "paired," which involves establishing a secure connection and exchanging information to recognize each other
- ❑ **Piconets:** When a group of Bluetooth devices are connected, they form a personal area network (PAN), also known as a piconet, where one device acts as the **master** and others as **slaves**, sharing the radio channel
- ❑ **Security:** Communications are encrypted to ensure data security, preventing unauthorized access